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Standard Test Method for

UNCONSOLIDATED, UNDRAINED COMPRESSIVE STRENGTH OF COHESIVE SOILS IN TRIAXIAL COMPRESSION[1]

This standard is issued under the fixed designation D 2850; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the unconsolidated, undrained compressive strength (or maximum principal stress difference) of cylindrical specimens of cohesive soils in undisturbed, remolded, or compacted conditions using constant rate of deformation (strain-controlled) application of the axial compression test load and where the specimen is subjected to a confining fluid pressure in a triaxial chamber. No drainage of the specimen is permitted during the test. The test method provides for the measurement of the total stresses applied to the specimen, that is, the stresses are not corrected for pore-water pressure. The total stress is the sum of the effective stress and the pore pressure.

1.2 This test method provides data for determining undrained strength properties and stress-strain relations for soils.

NOTE 1—The determination of the unconsolidated, undrained strength of cohesive soils without lateral confinement is covered by Test Methods D 2166.

NOTE 2—This test method does not provide a procedure for back pressure saturation of the test specimens. If back pressure saturation of the specimens is required, the test must be performed utilizing procedures and apparatus similar to those required for a consolidated undrained triaxial test. However, due to consolidation, which could occur during the saturation phase, this modified procedure is not truly unconsolidated. A test method for the consolidated undrained triaxial test is currently under development in Subcommittee D18.05.

NOTE 3—This test method does not include a procedure for obtaining pore pressure measurements. Furthermore, at the rapid strain rates used in this test method such measurements could be inaccurate. If pore pressure measurements are desired, alternative procedures such as the U.S. Bureau of Reclamation Method E-17 can be used.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 422 Method for Particle-Size Analysis of Soils[2]

D 653 Terms and Symbols Relating to Soil and Rock[2]

D 854 Test Method for Specific Gravity of Soils[2]

D 1587 Practice for Thin-Walled Tube Sampling of Soils[2]

D 2166 Test Methods for Unconfined Compressive Strength of Cohesive Soil[2]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[2]

D 2487 Test Method for Classification of Soils for Engineering Purposes[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 4220 Practices for Preserving and Transporting Soil Samples[?]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[?]

3. Terminology

3.1 *Definitions:*

3.1.1 *triaxial compression test*—a test in which a cylindrical specimen of soil encased in an impervious membrane is subjected to a confining pressure and then loaded axially to failure in compression (as defined in 3.2.1).

3.1.2 *principal stress difference or deviator stress*—the difference between the major and minor principal stresses in a triaxial test.

3.1.2.1 *Discussion*—The principal stress difference or deviator stress is equal to the axial load applied to the specimen divided by the corrected cross-sectional area of the specimen, as prescribed in Section 8. The major principal stress in the specimen is equal to the deviator stress plus the chamber pressure, and the minor principal stress in the specimen is equal to the chamber pressure.

3.2 *Descriptions of Terms Specific to This Standard*

3.2.1 *failure*—the failure stresses are taken as the stresses in the specimen corresponding to the maximum principal stress difference (deviator stress) attained or the principal stress difference (deviator stress) at 15 % axial strain, whichever is obtained first during the performance of a test.

3.2.2 *unconsolidated-undrained compressive strength*—the value of the maximum principal stress difference or deviator stress obtained during the test.

4. Significance and Use

4.1 In this test method, the compressive strength of a soil is determined in terms of the total stress, therefore, the resulting strength depends on the pressure developed in the pore fluid during loading. In this test method, fluid flow is not permitted from or into the soil specimen as the load is applied, therefore the resulting pore pressure, and hence strength, differs from that developed in the case where drainage can occur.

4.2 If the test specimens are 100 % saturated, consolidation cannot occur when the confining pressure is applied nor during the shear portion of the test since drainage is not permitted. Therefore, if several specimens of the same material

are tested, and if they are all at approximately the same water content and void ratio when they are tested, they will have approximately the same undrained shear strength. The Mohr failure envelope will usually be a horizontal straight line over the entire range of confining stresses applied to the specimens if the specimens are fully saturated.

4.3 If the test specimens are partially saturated or compacted specimens, where the degree of saturation is less than 100 %, consolidation may occur when the confining pressure is applied and during shear, even though drainage is not permitted. Therefore, if several partially saturated specimens of the same material are tested at different confining stresses, they will not have the same undrained shear strength. Thus, the Mohr failure envelope for unconsolidated undrained triaxial tests on partially saturated soils is usually curved.

4.4 The unconsolidated undrained triaxial strength is applicable to certain design situations in geotechnical engineering practice where the loads are assumed to take place so rapidly that there is insufficient time for the induced pore-water pressure to dissipate and for consolidation to occur during the loading period (that is, drainage does not occur). The unconsolidated undrained triaxial strength is used to determine strengths at the end of construction.

4.5 Compressive strengths determined using this procedure may not apply in cases where the loading conditions in the field differ significantly from those used in this test method.

5. Apparatus

5.1 *Axial Loading Device*—The axial compression device may be screw jack driven by an electric motor through a geared transmission, a hydraulic or pneumatic loading device, or any other compression device with sufficient capacity and control to provide the rate of loading prescribed in 7.5. When the loading device is set to advance at a certain rate of strain, the actual rate of strain shall not deviate by more than ±10 %. Vibrations due to the operation of the loading device shall be kept at a minimum.

NOTE 4—A loading device may be said to provide sufficiently small vibrations if there are no visible ripples in a glass of water placed on the loading platen when the device is operating at the speed at which the test is performed.

5.2 *Axial Load-Measuring Device*—The axial load-measuring device shall be a load ring, electronic load cell, hydraulic load cell, or any other load-measuring device capable of the accuracy prescribed in this section and may be a part of the axial loading device. The axial load-measuring device shall be capable of measuring the axial load to an accuracy of 1 % of the estimated axial load at failure.

5.3 *Chamber Pressure-Maintaining and Measurement Device*—The chamber pressure-maintaining and measurement device shall be capable of applying and controlling the chamber pressure to within ±1 % of the applied chamber pressure. This device may consist of a reservoir connected to the triaxial chamber and partially filled with the chamber fluid (usually water), with the upper part of the reservoir connected to a compressed gas supply; the gas pressure being controlled by a pressure regulator and measured by a pressure gage, electronic pressure transducer, or any other device capable of measuring to the prescribed tolerance. However, a hydraulic system pressurized by deadweight acting on a piston or any other pressure-maintaining and measurement device capable of applying and controlling the chamber pressure to the tolerance prescribed in this section may be used.

5.4 *Triaxial Compression Chamber*—An apparatus shall be provided in which the cylindrical specimen, enclosed by a membrane sealed to the specimen cap and base, may be placed and subjected to a constant hydrostatic fluid pressure. The apparatus shall include a bushing and piston, aligned with the axis of the specimen, through which the load from the axial loading device is transmitted to the specimen axially between the specimen cap and base. The bushing and piston shall be designed to minimize friction and lateral thrust to the specimen cap.

5.5 *Specimen Cap and Base*—An impermeable rigid cap and base shall be used to prevent drainage of the specimen. The specimen cap and base shall be constructed of a noncorrosive impermeable material, and each shall have a circular plane surface of contact with the specimen and a circular cross section. The weight of the specimen cap shall produce an axial stress on the specimen of less than 1 kN/m² shall be equal to the initial diameter of the cap and base shall be equal to the initial diameter of the specimen. The specimen base shall be coupled to the triaxial compression chamber so as to prevent lateral motion or tilting and the specimen cap shall be designed to receive the piston such that the piston-to-cap contact area is concentric with the cap. The specimen cap during shear shall not tilt more than 5°. The cylindrical surface of the specimen base and cap that contacts the membrane to form a seal shall be smooth and free of scratches.

NOTE 5—The stress produced by the specimen cap can exceed 1 kN/m² provided the test data is corrected for the effects of that stress.

5.6 *Deformation Indicator*—The deformation indicator shall be a dial indicator capable of measuring axial deformation to within 0.03 % of the specimen height and having a travel range of at least 20 % of the initial height of the test specimen, or any other measuring device, such as electronic deformation measuring devices, meeting these requirements of readability and range.

5.7 *Rubber Membranes*—The rubber membrane used to encase the specimen shall provide reliable protection against leakage. Membranes shall be carefully inspected prior to use, and if any flaws or pinholes are evident, the membrane shall be discarded. In order to offer minimum restraint to the specimen, the unstretched membrane diameter shall be between 90 and 95 % of that of the specimen. The membrane thickness shall not exceed 1 % of the diameter of the specimen. The membrane shall be sealed to the specimen base and cap by any method that will produce a positive seal. An equation for correcting the principal stress difference (deviator stress) for the effect of the stiffness of the membrane is given in 8.5.

NOTE 6—The membrane is typically sealed using O-rings with silicon grease between the cap and base and the membrane.

5.8 *Sample Extruder*—The sample extruder shall be capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube and with minimum disturbance of the sample. If the soil core is not extruded vertically, care should be taken to avoid bending stresses on the core due to gravity. Conditions at the time of sample removal may dictate the direction of removal, but the principal concern is to keep the degree of disturbance minimal.

5.9 *Specimen Size Measurement Devices*—Devices used to measure the height and diameter

of the specimen shall be capable of measuring the desired dimension to within 0.1 % of its actual length and shall be constructed such that their use will not disturb the specimen.

5.10 *Timer*—A timing device indicating the elapsed testing time to the nearest 1 s shall be used for establishing the rate of strain application prescribed in 7.5.

5.11 *Balances*—The balance used to weigh specimens shall determine the mass of the specimens to within 0.1 % of the total mass.

5.12 *Apparatus for Water Content*, as specified in Method D 2216.

5.13 *Miscellaneous Apparatus*—Specimen trimming and carving tools, membrane and O-ring expanders, compaction apparatus, and data sheets as required.

6. Test Specimens

6.1 *Specimen Size*—Specimens shall have a minimum diameter of 30 mm and the largest particle contained within the test specimen shall be smaller than ¼ of the specimen diameter. If, after completion of a test, it is found that oversize particles are present, indicate this information in the report of test data under remarks. Determine the average height and diameter of the test specimen using the apparatus specified in 5.9. Take a minimum of three height measurements (120° apart) and at least three diameter measurements at each of the quarter points of the height. The height-to-diameter ratio of the specimen shall be between 2 and 2.5.

NOTE 7—If large soil particles are found in the specimen after testing, a particle-size analysis in accordance with Method D 422 may be performed to confirm the visual observation and the results provided with the test report.

6.2 *Undisturbed Specimens*—Prepare undisturbed specimens from large undisturbed samples or from samples secured in accordance with Practice D 1587 or other acceptable undisturbed tube sampling procedures. Undisturbed samples shall be preserved and transported as outlined for Groups C or D samples in Practices D 4220. Specimens obtained by tube sampling may be tested without trimming, except for the squaring of ends, provided soil characteristics are such that no significant disturbance results from sampling and the specimen is uniformly circular. Handle specimens carefully to minimize disturbance, changes in cross section, or loss of water content.

If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut it off in small sections to facilitate removal of the specimen with minimum disturbance. Prepare trimmed specimens in an environment where the change in the water content of the soil is minimized (Note 8). Specimens shall be of uniform, circular cross section perpendicular to the axis of the specimen. Where pebbles or crumbling result in excessive irregularity along the outside edges of the specimen or at the ends, pack soil from the trimmings in the irregularities to produce the desired surface. As an alternative, the ends of the specimen may be capped with a minimal thickness of plaster of paris, hydrostone, or similar material. Where soil conditions permit, a vertical lathe accommodating the total sample may be used as an aid in trimming the specimen to the required diameter. Determine the mass and dimensions of the test specimen in accordance with 5.9 and 5.11. If the specimen is to be capped, determine its mass and dimensions before capping. Enclose the specimen in the rubber membrane and seal the membrane to the specimen base and cap immediately after preparation.

NOTE 8—A controlled high-humidity room is usually used for this purpose.

6.3 *Remolded Specimens*—Prepare the specimen by first thoroughly working the undisturbed specimen, which has been tested and is still encased in the rubber membrane, with the fingers. Then reform the specimen by forming within a mold having dimensions such that the remolded specimen dimensions will be equal to those of the undisturbed specimen. Exercise care to avoid entrapping air in the specimen. This will aid in obtaining a uniform unit weight, in remolding to the same void ratio as the undisturbed specimen, and in preserving the natural water content of the soil.

6.4 *Compacted Specimens*—Prepare specimens using the compaction method, predetermined water content, and unit weight prescribed by the individual assigning the test. Compacted specimens may be prepared by compacting material in at least six layers, using a pressing or kneading action, into a split mold of circular cross section having dimensions meeting the requirements of 6.1. Material required for the specimen shall be batched by thoroughly mixing soil with sufficient water to produce the desired water

content. After batching, store the material in a covered container for at least 16 h prior to compaction. Specimens may be molded to the desired density by either: (1) kneading or tamping each layer until the accumulative weight of the soil placed in the mold is compacted to a known volume or (2) by adjusting the number of layers, the number of tamps per layer, and the force per tamp. Scarify the top of each layer prior to the addition of material for the next layer. The tamper used to compact the material shall have an area in contact with the soil equal to or less than ⅓ the area of the mold. After a specimen is formed, with the ends perpendicular to the longitudinal axis, remove the mold and determine the mass and dimensions of the specimen using the devices described in 5.9 and 5.11. Perform one or more water content determinations on excess material used to prepare the specimen in accordance with Method D 2216.

Note 9—It is common for the unit weight of the specimen after removal from the mold to be less than the value based on the volume of the mold. This occurs as a result of the specimen swelling after removal of the lateral confinement due to the mold.

Note 10—Experience indicates that it is difficult to compact, handle, and obtain valid results with specimens that have a degree of saturation that is greater than about 90 %.

7. Procedure

7.1 Place the membrane on the membrane expander or, if it is rolled onto the specimen, roll the membrane onto the cap or base. Place the specimen on the base. Place the rubber membrane around the specimen and seal it at the cap and base with O-rings or other positive seals at each end. A thin coating of silicon grease on the vertical surfaces of the cap or base will aid in sealing the membrane.

7.2 With the specimen encased in the rubber membrane, which is sealed to the specimen cap and base and positioned in the chamber, assemble the triaxial chamber. Bring the axial load piston into contact with the specimen cap several times to permit proper seating and alignment of the piston with the cap. When the piston is brought into contact the final time, record the reading on the deformation indicator. During this procedure, take care not to apply an axial stress to the specimen exceeding approximately 0.5 % of the estimated compressive strength. If the weight of the piston is sufficient to apply an

axial stress exceeding approximately 0.5 % of the estimated compressive strength, lock the piston in place above the specimen cap after checking the seating and alignment and keep locked until application of the chamber pressure.

7.3 Place the chamber in position in the axial loading device. Be careful to align the axial loading device, the axial load-measuring device, and the triaxial chamber to prevent the application of a lateral force to the piston during testing. Attach the pressure-maintaining and measurement device to the desired chamber pressure and apply the pressure to the chamber fluid. Wait approximately 10 min after the application of chamber pressure before continuing the test.

Note 11—In some cases the chamber will be filled and the chamber pressure applied before placement in the axial loading device.

Note 12—Make sure the piston is locked or held in place by the axial loading device before applying the chamber pressure.

Note 13—The purpose of the waiting period is to allow the specimen to stabilize under the chamber pressure prior to application of the axial load.

7.4 If the axial load-measuring device is located outside of the triaxial chamber, the chamber pressure will produce an upward force on the piston that will react against the axial loading device. In this case, start the test with the piston slightly above the specimen cap, and before the piston comes in contact with the specimen cap, either: (1) measure and record the initial piston friction and upward thrust of the piston produced by the chamber pressure and later correct the measured axial load, or (2) adjust the axial load-measuring device to compensate for the friction and thrust. If the axial load-measuring device is located inside the chamber, it will not be necessary to correct or compensate for the uplift force acting on the axial loading device or for piston friction. In both cases record the initial reading on the deformation indicator when the piston contacts the specimen cap.

7.5 Apply the axial load to produce axial strain at a rate of approximately 1 %/min for plastic materials and 0.3 %/min for brittle materials that achieve maximum deviator stress at approximately 3 to 6 % strain. At these rates, the elapsed time to reach maximum deviator stress will be approximately 15 to 20 min. Continue

the loading to 15 % axial strain, except loading may be stopped when the deviator stress has peaked then dropped 20 % or the axial strain has reached 5 % beyond the strain at which the peak in deviator stress occurred.

7.6 Record load and deformation values at about 0.1, 0.2, 0.3, 0.4, and 0.5 % strain; then at increments of about 0.5 % strain to 3 %; and, thereafter at every 1 %. Take sufficient readings to define the stress - strain curve; hence, more frequent readings may be required in the early stages of the test and as failure is approached.

NOTE 14—Alternate intervals for the readings may be used provided sufficient points are obtained to define the stress - strain curve.

7.7 After completion of the tests, remove the test specimen from the chamber. Determine the water content of the test specimen in accordance with Method D 2216 using the entire specimen, unless representative cuttings are obtained for this purpose, as in the case of undisturbed specimens. Indicate on the test report whether the water content sample was obtained before or after the shear test, as required in 9.1.2.

7.8 Make a sketch, or take a photo, of the test specimen at failure and show the slope angle of the failure surface if the angle is visible and measurable.

8. Calculations

8.1 Calculate the axial strain, ϵ (expressed as a decimal), for a given applied axial load, as follows:

$$\epsilon = \Delta l / l_o$$

where:
Δl = change in length of specimen as read from deformation indicator, and
l_o = initial length of test specimen minus any change in length prior to loading.

8.2 Calculate the average cross-sectional area, A, for a given applied axial load as follows:

$$A = A_o/(1 - \epsilon)$$

where:
A_o = initial average cross-sectional area of the specimen, and
ϵ = axial strain for the given axial load (expressed as a decimal).

NOTE 15—In the event that the application of the chamber pressure results in a change in the specimen length, A_o should be corrected to reflect this change in volume. Frequently, this is done by assuming that

lateral strains are equal to vertical strains. The diameter after volume change would be given by $D = D_o(1 - \Delta L/L)$.

8.3 Calculate the principal stress difference (deviator stress), $\sigma_1 - \sigma_3$, for a given applied axial load as follows:

$$\sigma_1 - \sigma_3 = P/A$$

where:
P = measured applied axial load (corrected for uplift and piston friction, if required see 7.4), and
A = corresponding average cross-sectional area.

8.4 *Stress - Strain Curve*—Prepare a graph showing the relationship between principal stress difference (deviator stress) and axial strain, plotting deviator stress as ordinate and axial strain (in percent) as abscissa. Select the compressive strength and axial strain at failure in accordance with the definitions in 3.2.1 and 3.2.2.

8.5 *Correction of Strength Due to Stiffness of Rubber Membrane*—Assuming units are consistent, the following equation, or other acceptable equations, shall be used to correct the principal stress difference or deviator stress for the effect of the rubber membrane if the error in principal stress difference due to the stiffness of the membrane exceeds 5 %:

$$\Delta(\sigma_1 - \sigma_3) = \frac{4 E_m t \epsilon_1}{D}$$

where:
$\Delta(\sigma_1 - \sigma_3)$ = correction to be subtracted from the measured principal stress difference,
D = $\sqrt{\frac{4A}{\pi}}$ = diameter of specimen,
E_m = Young's modulus for the membrane material,
t = thickness of the membrane, and
ϵ_1 = axial strain.

8.5.1 The Young's modulus of the membrane material may be determined by hanging a 10.0-mm wide strip of membrane over a thin rod, placing another rod along the bottom of the hanging membrane, and measuring the force per unit strain obtained by stretching the membrane. The modulus value may be computed using the following equation assuming units are consistent:

$$E_m = \frac{FL}{A_m \Delta L}$$

where:

E_m = Young's modulus of the membrane material,

F = force applied to stretch the membrane,

A_m = twice the initial thickness of the membrane multiplied by the width of the membrane strip,

L = unstretched length of the membrane, and

ΔL = change in length of the membrane due to application of F.

A typical value of E_m for latex membrane is 1400 kN/m².

NOTE 16—The effect of the stiffness of the membrane on the lateral stress is usually, assumed to be negligible.

NOTE 17—The correction for rubber membranes is based on simplified assumptions concerning their behavior during shear. Their actual behavior is complex and there is not a consensus on more exact corrections.

8.6 Calculate the major and minor principal total stresses at failure as follows:

σ_3 = minor principal total stress = chamber pressure, and

σ_1 = major principal total stress = deviator stress at failure plus chamber pressure.

8.7 Calculate the initial degree of saturation of the test specimen using the initial mass and dimensions.

NOTE 18—The specific gravity determined in accordance with Test Method D 854 is required for calculation of the degree of saturation, or an assumed value may be used provided it is noted in the test report that an assumed value was used.

9. Report

9.1 The report shall include the following:

9.1.1 Identification and visual description of specimen, including soil group name, symbol, whether specimen is undisturbed, remolded, or compacted, and the like. Also include specimen identifying information, such as project, location, boring number, sample number, depth, and the like. Visual descriptions shall be made in accordance with Practice D 2488.

9.1.2 Initial dry unit weight and water content (specify if the water content specimen was ob-

tained before or after the shear and from cuttings or the entire specimen).

9.1.3 Degree of saturation.

9.1.4 Height and diameter of the specimen.

9.1.5 Height to diameter ratio.

9.1.6 The value of the compressive strength and the values of the minor and major principal stresses at failure.

9.1.7 Stress - strain curve as described in 8.4.

9.1.8 Axial strain at failure, in percent.

9.1.9 Average rate of axial strain to failure, percent per minute.

9.1.10 Liquid and plastic limits, if determined, in accordance with Test Method D 4318.

9.1.11 Sketch or photo showing type of failure, that is, bulge, diagonal shear, and the like.

9.1.12 Particle-size analysis, if determined, in accordance with Method D 422.

9.1.13 If a membrane correction was used, the report shall state that a membrane correction was used to adjust the compressive strength and must indicate the membrane correction equation that was used.

9.1.14 In a remarks section note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained, for example, slickensides, stratification, shells, pebbles, roots, or brittleness.

10. Precision and Bias

10.1 No method presently exists to evaluate the precision of a group of triaxial compression tests on undisturbed specimens due to specimen variability. Undisturbed soil specimens from apparently homogeneous soil deposits at the same location often exhibit significantly different strength and stress - strain properties.

10.2 A suitable test material and method of specimen preparation have not been developed for the determination of laboratory variances of compacted specimens due to the difficulty in producing identical cohesive soil specimens. No estimates of precision for this test method are available.